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TEAM PERFORMANCE ANALYSIS OF A COLLABORATIVE SPATIAL ORIENTATION MISSION IN MARS ANALOGUE ENVIRONMENT.

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Abstract

As highlighted by human factors experts of the IAA, complementary studies have to be carried out in the field of human sciences to better understand psychological and sociological issues in long duration spaceflight and in isolated and extreme planetary environment. In order to minimize operational risks, efficient communication, problem solving capability and teamwork efficiency, which are considered key behavioural competencies by NASA, have to be tested. It is proposed here to assess the collaboration performance of astronauts in the context of a team spatial orientation task in planetary-analog environments. The experiment was originally designed and tested at the Mars Desert Research Station (crew 185, December 2017). Interestingly, some failures have been observed due to imperfect spatial representation, uncertainties and some communication problems. A similar experiment has been carried out using a virtual environment. N=62 participants have been paired up. Both teammates must collaborate to send a rover to a specific location on a computer simulation of the Mars surface. One person, the astronaut, drives the rover in the virtual environment, orally guided by the captain staying at the base. Every 45 seconds, each participant is asked to mark on his map the location he believes the rover to be. Similarity of teammates spatial shared situational awareness and their accuracy have been used to objectively assess the team performance. Answers to a post-experiment questionnaire have been used to assess perceived communication behaviours of the team. Successful and Unsuccessful teams are compared. Interesting results are presented and discussed. Remarkably, significant differences in terms of Spatial SSA and communication behaviours appeared.

Keywords: Team performance, communications, situation awareness

1. Introduction

Human factors issues have to be addressed before undertaking the first human mission to Mars [15]. Several authors broached the subject and identified psychological and sociological problems that could happen during such a mission [7,9]. As a two-way trip would last up to 3 years, it is crucial to understand the mechanisms that determine the success or failure of the mission. Yet how is it possible to make sure that the astronauts chosen for the expedition cooperate in the best manner possible? Astronauts can be trained to specific generic behavioural competencies in communication, collaboration, stress management, etc. This is what is proposed by NASA for ISS missions [10]. However, human factors difficulties strongly depend on the type of activities [10]. On the surface of the planet, numerous complex outdoor activities will have to be carried out using robots and surface vehicles [5,14]. According to several authors, most human errors are linked to situation awareness (SA) degradation and bad representation sharing [1,2,13,16,17,18,19]. In order to prepare the astronauts and reduce the risks, it is important to better understand these issues and to train the astronauts accordingly. Training can be carried out in analogue terrains on Earth or in virtual reality [3]. It is proposed here to study communication and team performance during a collaborative exploration task between two persons, the first playing the role of mission control and the second an astronaut driving a pressurized rover in a virtual environment representing the surface of Mars. In order to assess SA and representation sharing, it was asked each participant to mark their estimated position on a map. A questionnaire was also used to get information on their feeling of the team performance and communication efficiency. Section 2, the task and the protocol of the experiment are explained. In a previous paper, the focus was on the SA accuracy and the similarity of the spatial representation thanks to the comparison of the positions. It is proposed to focus here on the representation of the task and the behaviours through an analysis of the answers to the questionnaire. This analysis is presented Section 3. In the conclusion, a synthesis of the results is provided with some recommendations

2. Methodology

2.1 Task

62 volunteers, 38 women and 24 men aged between 18 and 43 years old (M=21.6) were recruited in Bordeaux University's campus. Subjects were paired up to perform a collaborative orientation task. They were asked to collaborate to retrieve a white rock hidden in a computer simulation of a Martian environment. Each of the two teammates was assigned a specific role. First one, the Astro (for astronaut), drives a rover in the virtual environment. His teammate, called CapCom, does not see the environment and is in charge of orally guiding Astro towards the desired location. They were both given the same paper map to orient themselves. The location of the target was indicated on CapCom's map while he did not have access to images of the simulation. None of them had previous knowledge of the environment and they were separated so as to be able to communicate only orally.

2.2 Material

Each participant is given a A4-size paper map of the simulation environment, see Fig.1. The starting point of the rover and its orientation were indicated on each map. The position of the white rock target was only stipulated on the CapCom map. No grid system nor scale were present. Maps were given in the exact same orientation to both participants but they were not aware of that. The simulation software has been developed internally using a Unity platform. The simulation was run on a 24" monitor. The 18-questions post-experiment questionnaire had to be filled up using an online form.

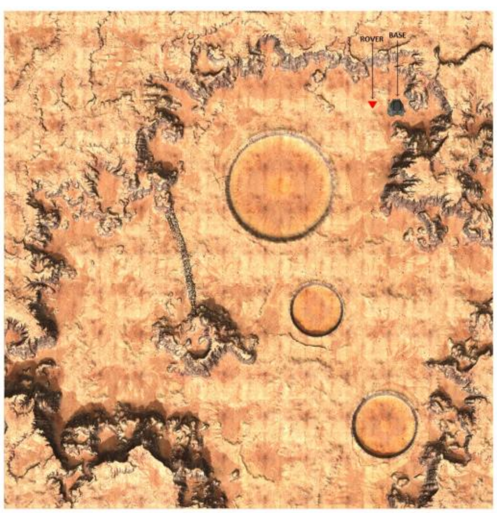

Fig. 1. Map of the environment. The rover is located close to the upper-right corner.

2.3 Design and Procedure

Before the experiment, each teammate was assigned the role of either Astro or Capcom. Then they were assigned a work station and instructions were given depending on their role. The map was handed to them with the starting position of the rover and initial orientation indicated on it. The Astro task was to navigate the rover using a keyboard (first person view of the environment, as he was the driver, see Fig. 2). They were told that the goal was to find a white rock as quickly as possible. During the whole experiment they were allowed to communicate only orally. CapCom was instructed not to directly inform Astro the precise geographical position of the rock (not allowed to say "the rock is on the top left corner of the map"). He can only provide geographical cues and general information to orient him in real time. Importantly, every 45 seconds, the simulation was paused and each teammate was asked to mark down on his map the estimated position of the rover (Position Evaluation Point). Teammates were not allowed to communicate during this phase of the experiment. After 15 minutes, if the rock was not found, the mission was considered a failure and the simulation was stopped.

Fig. 2: Astro is driving the rover in the virtual environment (left) while visually separated from Capcom guiding him (right).

After the experiment, they answered a questionnaire without communicating with their partner. 18 questions have been asked. They can be split into three categories. 5 background questions cover general information about the person and habits concerning the task and the use of simulators. The second category is composed of 8 Likert-type questions evaluating their perceived performance both at an individual and team level. Finally, 5 questions aim at gathering subjective feedback on their teamwork and communications behaviours.

Participants have no mean to compare themselves to other groups since they do not have access to their time performance nor to the one of previous groups.

2.4 Metrics

In a previous paper, we established a link between completion time and the mean SA accuracy within the successful group [11]. In this paper, we propose to conduct a comparison between successful teams and teams who failed at the task, through 5 variables. In the context of a spatial orientation task, we consider spatial situation awareness as the part of one's global understanding of the situation relative to the position in space of the teammate or of oneself [8]. Shared SA is assessed through two objective measurements. (1) SSA Accuracy measures how accurate their representation is compared to the reality and (2) SSA Similarity measures how much teammates share a common representation of the spatial situation. These measures are based on the position evaluation points. Their construction is detailed in Section 3. From the post-experiment questionnaire, 3 subjective evaluations are analysed, (1) the similarity of perceived team and teammate's performance, (2) the similarity of perceived repartition of communications and (3) the similarity of perceived repartition of questions during the task.

3. Results

Among the 31 teams, 3 crashed the vehicle and did not finish the task. They have been removed from the following analysis. 8 of the remaining 28 pairs failed to find the rock under 15 minutes. For the 20 successful teams, mean completion time is 450.5s (min = 274s; max = 648s, SD = 102.56). Our Analysis focuses on these two "Unsuccessful" and "Successful" groups of performance.

3.1 Shared Spatial

SSA is quantitatively assessed through two spatial metrics extracted from the 628 Position Evaluation Points generated by the 56 participants (two points every 45s of simulation). (1) Spatial SSA accuracy is measured by comparing the estimated position marked by the participant to the real position recorded by the simulation. Individual accuracies of teammates are then averaged to evaluate the SA Accuracy of the team. The lower the value, the more accurate the SSA is. (2) SSA similarity is measured as the physical distance between the positions marked by teammates for a same position evaluation point. Each Capcom point was matched to the corresponding Astro one. For each pair of points, the distance between them is calculated. Then for each team a single metric is built by averaging all distances of the list of paired points that have been marked. The shorter the distance between the two points, the more similar, thus shared, the representation of the spatial position is between teammates.

These distances are expressed in Unity measurement metric (1 unit = 0.083% of the map). Boxplot comparisons of the two metrics between groups are illustrated in Fig. 3 and Fig. 4.

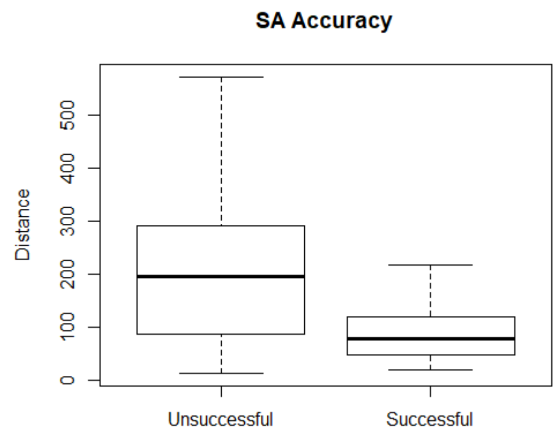

Fig. 3. Boxplot Comparison of SA Accuracy measures between Successful and Unsuccessful teams

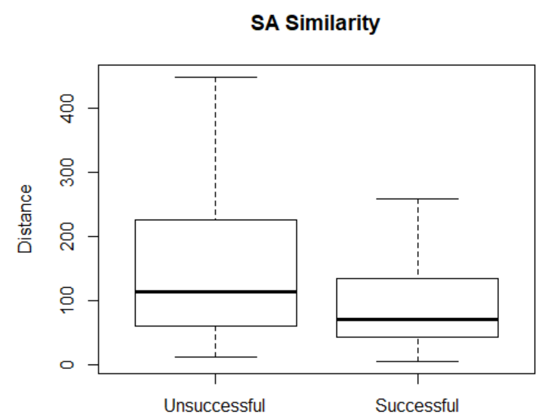

Fig. 4: Boxplot Comparison of Mean SA Similarity measures between Successful and Unsuccessful teams

We observe a better performance both in terms of mean SA accuracy and SA similarity from successful teams (mean Accuracy = 106.79 vs 211.66, mean Similarity = 94.87 vs 171.24), also characterized by a lower standard deviation (Accuracy SD = 86.74 vs 142.99, Similarity SD = 71.41 vs 156.22). This result shows that successful teams generally share a more common and more accurate understanding of the situation than unsuccessful teams. T-tests (with respectively p-value = 2.92e-12 < 0.01, p-value = 5.826e-07 < 0.01) confirm the relevant difference in terms of spatial SSA performance between unsuccessful and successful teams.

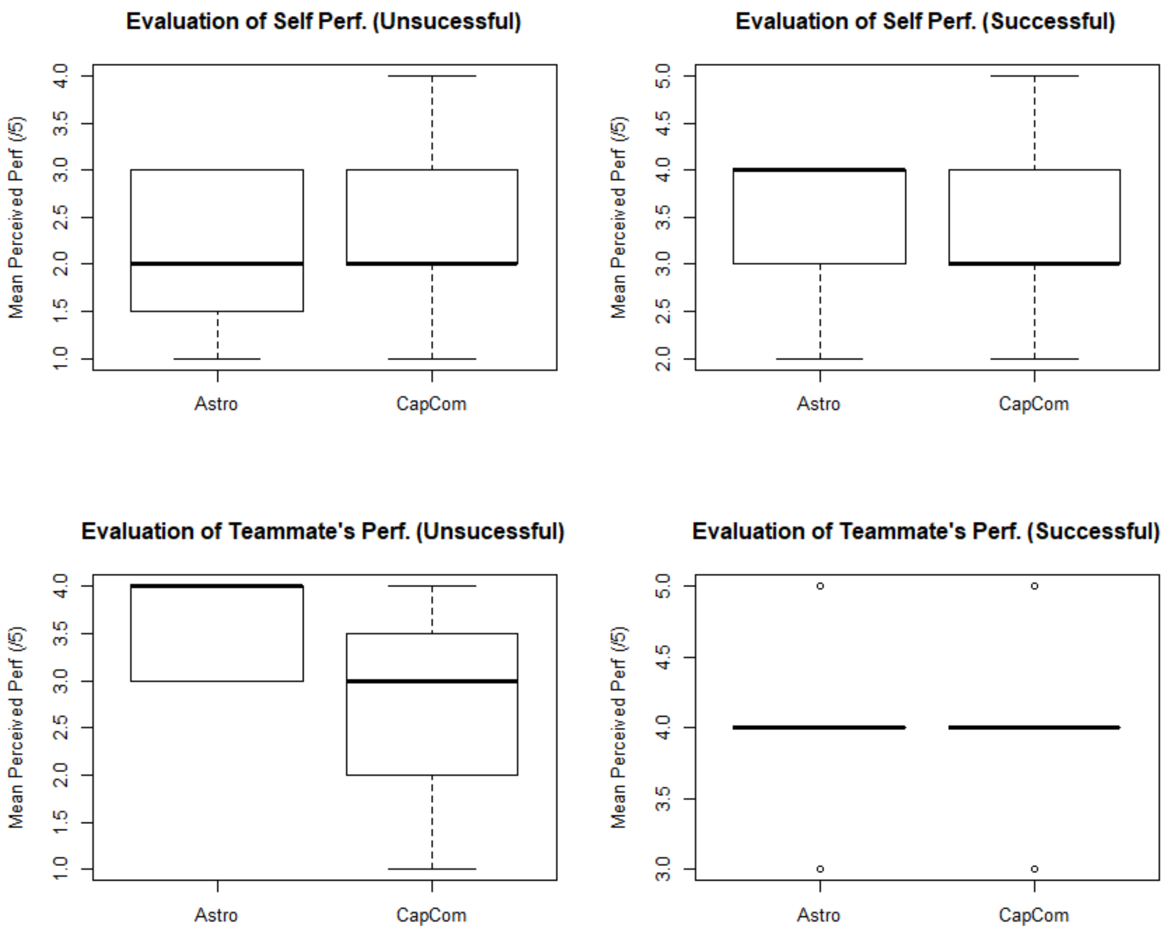

Fig. 5. Perceived Self and Teammate's performance according to role in Unseccessful (left column) and Successful (right column) teams.

3.2 Perceived Team Performance

The perceived performance of the team is obviously biased by the success or failure to find the rock. Beyond the trivial observation that successful teams rate their performance better than unsuccessful ones, it is interesting to explore the influence of the subject's role in the evaluation of self and teammate's performance. Each participant answered two questions. The first was to evaluate his teammate's performance and the second his own performance, on a scale from 1 to 5 (1 being the lowest and 5 the highest). The results are presented Fig. 5. The top row represents the subject's own performance evaluation for successful and unsuccessful teams and the bottom row represents the evaluation of the teammate's performance for the two groups of interest. An interesting trend appears when looking at the differences between self and teammate's performance evaluation. As can be observed Fig. 4, evaluations of self and teammate's performance in successful teams seem to be similarly distributed between Astro and CapCom. On the other hand, unsuccessful teams' Astros tend to rate their teammate's performance better than CapCom does. Similarly, they also tend to evaluate themselves less performant than their teammate.

The result of this intra-group analysis would suggest Astros are more inclined to take the responsibility of the failure than CapComs. A possible explanation is the existence of an implicit hierarchical link perceived by Astro. In the context of a spatial orientation task, Capcom's guidance might be interpreted as instructions by Astro. CapCom being the instructor knowing where to go, Astro might believe failure as resulting from his wrong understanding of CapCom instructions and his inability to provide appropriate feedback. He seems therefore more inclined to endorse the responsibility of the failure, while Capcom would not necessarily share the same feeling.

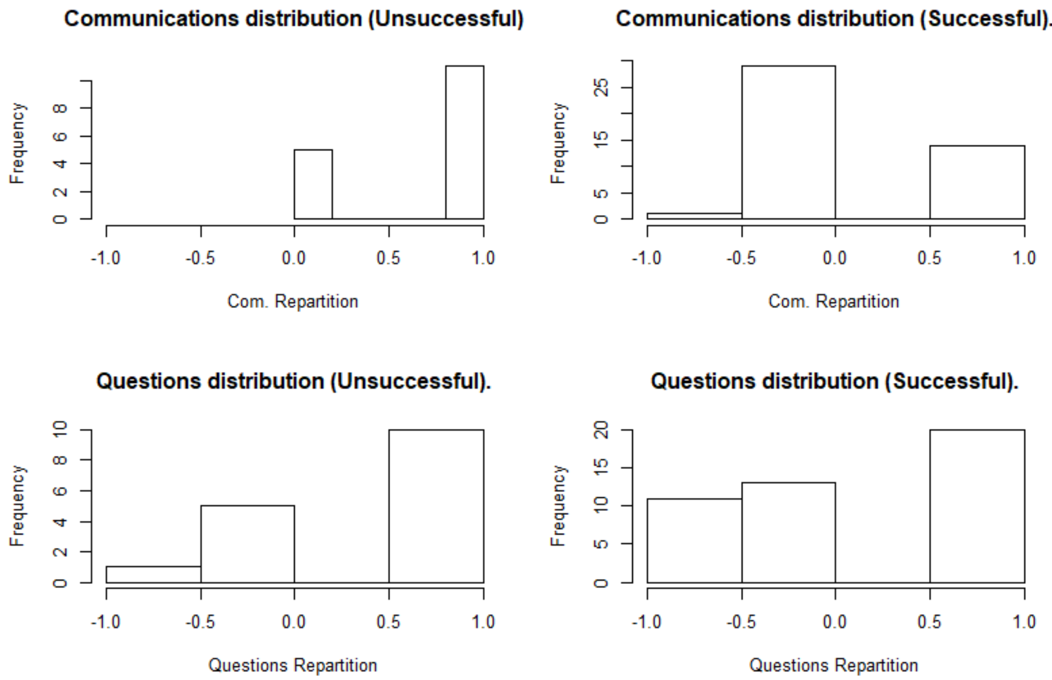

Fig. 6. Perceived communications and questions repartition within teams between Astro (-1) and CapCom (1)

3.3 Communications strategies

Communication is known to be a central process in teamwork and performance [12,17]. It is a necessary process for the construction of a common understanding of the team's situation. As stated earlier, answers to two questions have been studied, concerning (1) the perceived distribution of general communications ("who spoke the most?") and (2) the perceived distribution of questions ("Who asked the greater number of questions?"). Answers have been converted from "Myself/Balanced/Teammate" to -1 for Astro, 0 for Balanced and 1 for Capcom. Thus for each team we obtain a score ranging between -1 and 1, representing the average perceived distribution of communications and questions. Fig. 6 represents histogram visualizations of the repartition of the answers between Astro (-1), Balanced (0) or Capcom (1), for Successful (right column) and Unsuccessful teams (left column).

Members of unsuccessful teams seem to agree on communications and questions being more directed by Capcom, while successful teams tend to agree more on a more balanced repartition of the communication strategy. Means by groups are presented in Tab 1.

	Successful	Unsuccessful
Communications	0.2955	0.6875
Questions	0.2045	0.5625

Tab. 1. Average perceived communication distribution

3.4 Observations

The results presented in previous paragraphs find echoes in the qualitative observations made during the experiment. Although each team presented specific communication behaviours, some were generally more communicative than others. It has been noticed that Capcom is the one who, in general, speaks the most. However, when Astro sends appropriate feedbacks to Capcom by communicating on his environment and giving relevant geographical cues, we noticed that participants are better able to develop and keep a common vision of the spatial situation. Thus, we observed that the teams' performance tends to increase when the two teammates actively interact. Conversely, if the astronaut and CapCom are reluctant to communicate or if the communication is unbalanced, the success of the experiment is more uncertain. This observation is in perfect agreement with previous results concerning the importance of a balanced communication strategy for the success of the mission.

The atypical landscape of Mars and the lack of common references from the outset sometimes lead to confusion and ambiguities. In order to perform well in such a complex and unusual environment, several teams intuitively built a common language, based on a shared designation of landmarks and landscape specificities seen on the map.

Although observations showed that a good communication is essential for a success of the mission, it is not always sufficient. What is also needed is a constant information sharing throughout the experiment by both participants with the use of appropriate words and expressions, eventually reconceptualised, to make sure that the language and the representations are correctly shared. Importantly, Astro and CapCom must establish a clear common language early in the mission.

4. Conclusion

A simulated Mars exploration experiment has been conducted. Objective SSA metrics have been used to quantify team performance in terms of SSA accuracy SSA similarity. A subjective assessment has also been carried out using a post-experiment questionnaire. A total of 5 metrics allowed us to better understand behavioural differences and communication feelings between successful and unsuccessful teams. Several key points have been highlighted in this study:

The geographical description of a rocky region is difficult. Several teams failed because the description was approximate, the language was not completely shared and the astronaut was not able to provide sufficient details and valuable information to his partner on the current position. The consequence was a poor sharing of geographical representation. Our recommendation is to train the astronauts working together in the specific context of exploration, using appropriate words and expressions to describe the zone, the direction and speed of move and what is expected next.

There is an imbalance feeling in terms of responsibility and distribution of communication that is accentuated for the teams who failed to find the rock. The person playing the role of astronaut feels more responsible of the failure than his partner, while the partner would not necessarily share the same opinion. As a consequence, failure may have a negative impact on representation sharing and the cohesion of the team. In order to mitigate the effect, we recommend a training programme testing failure issues and appropriate counter measures to help the team preserving a high level of cohesion.

Some observations made during the experiments raise other questions. It has been noted that when an astronaut is unsure of where he is, this is reflected in his voice and can influence CapCom's direction. Thus, participants' behavioural attitudes could be another explanation for the success or failure of the mission. Kanas gives behavioural recommendations for this type of mission and the relations that teammates should maintain [7]. Finally, this study is also in line with NASA recommendations on training astronauts to behavioural competencies, especially for team working, communication and problem solving [10].

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